The University of Washington
Department of Chemistry

PRESERVATION OF IRON AND STEEL BY MEANS OF PASSIVIFYING FACTORS

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BY

THOMAS GORDON THOMPSON

L. C.

A Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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PRESERVATION OF IRON AND STEEL BY MEANS OF PASSIVIFYING FACTORS.

PASSIVITY.

When iron is immersed in solutions of chromic acid or potassium dichromate[1] for a few hours, treated with concentrated nitric acid or made the anode of an electric circuit in certain electrolytes, it becomes very inert. This phenomenon is known as passivity. Thus, for example, if a piece of iron or steel be placed in a solution of copper sulphate for a brief period, metallic copper will deposit upon the surface. If, however, the iron has been "passivified" by immersion in potassium dichromate or concentrated nitric acid, this reaction will not take place until the passivity has been destroyed. A further test for passivity is found in the fact[2] that the iron will not dissolve in nitric acid having a specific gravity of 1.20. Should iron be placed in concentrated nitric acid, the metal will begin to go into solution rapidly and then suddenly all chemical action will cease. Upon applying the above tests it will be found that the iron is in the passive state. If iron be made the positive electrode and placed in certain electrolytes and the amount of current flowing is sufficient, it will be noted that the iron will not go into solution according to Faraday's law. The iron will be passivified, the rate of solution reduced to a minimum, and bubbles of oxygen will arise from the anode.

Many explanations of this peculiar phenomenon have been offered, and the subject has claimed the attention of a vast number of investigators. No really satisfactory explanation, generally acceptable and capable of explaining the passive condition of metals under all circumstances, has, however, ever been advanced. Many investigators are supporters of the so-called oxide and gaseous film theories. A complete bibliography of the literature relating to passivity up to 1907 is given by Heathcote[3] and by Byers.[4] A symposium, "The Passivity of Metals," published by the Faraday Society in 1913, gives outlines of the more recent work upon this subject. A very clear and comprehensive chapter, "The Passive State of Iron," is given by J. Newton Friend in his interesting book, "The Corrosion of Iron and Steel."

That other metals besides iron may be rendered passive has been pointed out from time to time by various investigators. Thus Dustan and Hill[5] describe means for producing the passive state of zinc, together with a number of other metals. The effect of potassium dichromate upon zinc, when used as a galvanising agent, will be discussed in the experimental portion of this Report.

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[1] Dunstan and Hill (Jour. Chem. Soc., vol. 99, pp. 1833-53) have demonstrated that many other salts besides the dichromates may be utilised as passivifying agents.
[2] Heathcote, Jour. Soc. Chem. Ind., 1907, vol. 26, p. 899.
[3] Heathcote, Jour. Soc. Chem. Ind., 1907, vol. 26, p. 899.
[4] Jour. Am. Chem. Soc., 1908, vol. 30, p. 1718.
[5] Jour. Chem. Soc., vol. 99, pp. 1853-67.

PASSIVITY AND ITS RELATION TO THE CORROSION OF IRON AND STEEL.

Passivifying Agents as Pigments.

Although the phenomenon of passivity has been known since 1794, no attempt was made until quite recently to make use of this peculiar fact as a means for preventing or inhibiting the corrosion of iron and steel. In 1895 M. P. Wood[1] called attention to the valuable properties possessed by insoluble and basic chromates when used as protective coatings for iron and steel. The use of such materials, when properly applied, has been confirmed by all investigators in this particular field. The work of Cushman has done much to demonstrate the value of chrome pigments.

Soluble Passivifying Agents in Steam Boilers.

The corrosion of steam boilers takes place under conditions very different from those encountered in the ordinary corrosion of iron and steel. The gases dissolved in the boiler water at atmospheric temperatures are rapidly removed, to a very large extent, upon heating, thereby decreasing the relative corrosivity of the water. However, other factors are present that will stimulate corrosion within the boiler. Briefly, these are the lack of homogeneity of the boiler plates, contact of the plates with dissimilar metals, the effect of strains, and the influence of dissolved salts. The nature of these dissolved salts determine to a great extent the corrosive action that goes on within the boiler.

From the work of Grave[2] and Moseley[3] it might be concluded that the chemical composition of the boiler plates, their lack of homogeneity, and the effect of strains would have very little to do with the ease with which the plates could be passivified.

The use of soluble chromates, such as potassium dichromate, as a means for preventing corrosion in boilers, was first recommended by Cushman.[4] He suggested the use of 5 lbs. of potassium dichromate to 1500 gallons of water. When this was tried on a commercial basis, it was found that the potassium dichromate had practically no influence in limiting corrosion. Archbutt[5] found that when potassium dichromate was added to the concentrated boiler water, corrosion was not prevented, "especially in locomotive boilers where metallic copper is in contact with the boiler." Under such conditions it would be impossible to maintain the passive state. The exact nature of the dissolved salts was not stated. Friend and Brown[6] have studied the effect of potassium dichromate and potassium chromate in varying concentrations in a number of solutions of sodium chloride ranging from fairly dilute to saturated. Tests were run for a few days

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[1] Trans. Am. Soc. Mech. Eng., vol. 16, p. 671.
[2] Z. physik Chem., vol. 77, pp. 513-76.
[3] Jour. Am. Chem. Soc., 1915, vol. 37, pp. 2326-34.
[4] United States Department of Agriculture, Office of Public Roads, Bulletin No. 30.
[5] Engineering, vol. 93, p. 824.
[6] Journal of the Iron and Steel Institute, 1911, No. I, p. 125.

at room temperature and at 95° C. With the potassium dichromate in sodium chloride corrosion took place readily both in the cool and hot solutions; and it was found that corrosion increased with the increase in concentration of the dichromate. However, with potassium chromate, increase in concentration of this salt in the presence of the sodium chloride caused decrease in the rate of corrosion. The point at which corrosion was practically eliminated corresponded with the presence of an amount of dichromate which would have cost so much on a commercial basis as to make its application prohibitive. The tests of Friend and Brown at 95° were conducted for just three days, and during that time the solutions were heated only twelve hours a day, the solutions being allowed to cool to room temperature over night. While this treatment stimulated corrosive action, the results do not represent the true action of sodium chloride and potassium dichromate at 95° C.

As the great majority of boiler waters are practically free from chlorides, it seems probable that corrosion would be inhibited in waters containing sulphates alone if the water were treated with proper amounts of potassium dichromate. No quantitative data has yet been secured with mixed solutions of varying strengths of sulphates and potassium dichromate. Cushman[1] has shown qualitatively that with the increase of copper sulphate in solutions containing uniformly small amounts of potassium dichromate, the rate at which the copper was deposited was increased.

Anodic Passivity.

The possibility of making a boiler the anode in an electric circuit was suggested by Byers and Voris.[2] They were able to keep iron passive when it was used as an anode and placed in an electrolyte consisting of sodium chloride and potassium dichromate, there being forty times as much potassium dichromate as sodium chloride. The electrolyte was heated so that a pressure of from 20 to 50 lbs. per square inch was obtained. As there are so many factors that would tend to destroy this passivity in an ordinary steam boiler, it therefore seems very doubtful whether this form of passivity would be of any real practical value. With the increase in concentration of the boiler water, the increase in the amount of the potassium dichromate would have to be forty times that of the sodium chloride, and this very fact would render the cost of operation impossible. No work has yet been done showing the effect of the dichromate with the various sulphates commonly found in boiler waters, when the iron or boiler is made the anode in an electric circuit.

PURPOSES OF THIS RESEARCH.

Since the corrosion problem is so vast in extent, the author has limited himself to studying the means for preventing corrosion in steam boilers and receptacles for containing water for purely industrial purposes. The object

[1] Cushman and Gardner, "Corrosion and Preservation of Iron and Steel," p. 113.
[2] Jour. Am. Chem. Soc., 1912, vol. 34, pp. 1368-79.

of this research is to study the effect of various passivifying agents upon the rate of corrosion of different grades of iron in solutions of salts commonly occurring in boiler waters. The experimental work may be divided into four parts:

First: To ascertain the effect of varying amounts of potassium dichromate in solutions of different concentrations of sodium chloride, sodium sulphate, calcium sulphate, magnesium chloride, and magnesium sulphate at room temperature and at the temperature of boiling water.

Since the publication of the suggestion of the use of potassium dichromate as a means for preventing boiler corrosion, many text-books have been published which mention the use of potassium dichromate as a preventive for corrosion. It is the aim of the author to present sufficient data to establish definitely the truth or fallacy of this statement.

Second: To determine the efficiency of di-sodium phosphate as an inhibitive agent, the samples of iron and steel being placed in the above-mentioned solutions.

Third: To secure data regarding the action of zinc or galvanised iron in various solutions of sodium chloride and sodium sulphate containing varying amounts of potassium dichromate.

Fourth: To determine the practicability of keeping iron passive with potassium dichromate in the presence of the salts characteristic of boiler waters, when the iron is made the anode in an electric circuit and heated to a pressure varying from 120 lbs. to 150 lbs. per square inch.

EXPERIMENTAL.

The Nature and Preparation of the Samples of Iron and Steel.

The test-pieces used in all the following experiments consisted of a commercially pure iron and a low carbon steel, both of which had been rolled into sheets. The author is indebted to the American Rolling-Mill Company of Middletown, Ohio, who kindly supplied him with samples of their manufacture. The following shows the composition of the test-pieces:

	Commercially Pure Iron. Per Cent.	Low Carbon Steel. Per Cent.
Carbon	0.012	0.112
Phosphorus	0.004	0.045
Silicon	0.001	0.003
Sulphur	0.017	0.052
Manganese	0.015	0.388

For the corrosion tests, plates having a surface of 42 square centimetres were cut from the sheets, the plates being 8 cm. × 2½ cm. After cutting, a small hole was punched at the top of each plate so that it could be attached to a thread and suspended in solution. The plates were then numbered and pickled in a solution of dilute sulphuric acid until all foreign matter was removed by washing rapidly and thoroughly in water and then

treating with alcohol, ether, and finally with gasoline. After the latter had evaporated from the surfaces of the plates by holding them over a source of indirect heat, they were placed in desiccators containing calcium chloride and eventually weighed.

Preparation of Solutions.

Normal solutions of sodium chloride, sodium sulphate, magnesium chloride, and magnesium sulphate, and a saturated solution of calcium sulphate at 20° C. were made. From the first four solutions, N/10, N/100, and N/1000 solutions were prepared. A solution of potassium dichromate containing 100 grammes of the salt per litre and a normal solution of di-sodium phosphate were also made. Small amounts of these solutions were measured into the bottles in which the individual corrosion tests were to be run, so that when the other solutions were introduced they would also contain either a thousandth or a hundredth part of an equivalent weight of potassium dichromate or sodium phosphate. Amounts of these two latter substances were weighed out and placed in the various solutions so that they gave strengths of either N/10 or N/5.

In mentioning the normality of a potassium dichromate solution no reference is meant to its oxidizing power. A normal solution of the dichromate is considered here as containing half the gramme molecular weight.

Apparatus.

In running the corrosion tests at room temperature, one plate was placed in each bottle. The bottles were of 300 cubic centimetres capacity, and were arranged in such a manner as to permit the passage of a slow stream of air through the solution. Five of these bottles were placed in series without the slight increase in pressure in the first few bottles having any effect upon the rate of corrosion. The outlet tube was so far above the surface of the solution that any danger of particles of the liquid being carried over into the next bottle was practically eliminated.

The apparatus used for determining the rate of corrosion at the temperature of boiling water consisted of three large tin-plated tubs, in which the bottles containing the individual test-plates were placed. These tubs were heated by means of gas-burners, the water being supplied by means of a constant leveling device shown. Two of these devices were utilized for each tub, so that an accident to one would prevent the water from boiling away during the night. The bottles containing the plates were stoppered with wooden plugs, which had previously been steamed and then wrapped with tinfoil. These plugs were loosely fitted in order that the volume of gases could regulate itself without difficulty upon heating. A wooden rack supported the bottles within the tub. A cover, with a few small holes for the escape of steam, fitted securely over the top of the apparatus.

Conditions Under Which the Tests were Run.

In order to promote corrosion, should it occur, as rapidly as possible at room temperature, air was slowly bubbled through the solutions. The air was thoroughly washed in a series of wash bottles and permitted to pass through the solutions ten hours every day. This produced two important factors, namely, keeping the solutions saturated with oxygen and insuring the homogeneity of the liquids by constant stirring. All the tests were performed in a laboratory free from direct sunlight.

The bottles used to contain the solutions and test-plates for treatment at 100° C. were subjected to the action of boiling water for twenty hours a day for two weeks, before they were utilised for running the corrosion tests. During this time they were removed each day from the tub, emptied, cooled, and washed, then refilled and returned to the tub. The test-plates were not suspended in the solutions but were laid diagonally across the lower end of the bottle, with just the four corners touching the sides.

Cleaning the Test-Plates.

The rust which had collected on the test-plates run at room temperature was removed by treatment with either ammonium citrate or dilute sulphuric acid. Ammonium citrate, after treatment for a little time, removed the rust from the plates immersed in solutions containing no potassium dichromate or sodium phosphate, or very small amounts of these substances. Sulphuric acid had to be resorted to in order to remove the rust formed on some of the plates which had been in solutions containing N/10 and N/5 dichromate. In cases of this nature the rust was always in the form of hard minute spots. With the solutions containing the larger amounts of sodium phosphate, the corrosive material was of a peculiar nature, it being a dull green colour which always occurred in the form of streaks or large spots on the metal. These streaks and spots could be easily removed by gently rubbing with the fingers. After cleaning and washing the plates were dried in the manner previously described.

With the tests run at the temperature of boiling water it was impossible to clean the plates. Long immersions in ammonium citrate for two and three days had no desirable effect. On the other hand, if the plates were treated with sulphuric acid, part of the very thin scaly material covering the plate would be removed while the remainder would still be intact, and before this could be removed portions of the exposed metal would begin to dissolve. After a number of various attempts to clean these plates, it was finally decided, after washing with water and alcohol and drying, to weigh them directly. In the great majority of cases, no test for iron was obtained in the solutions, and thus weighing, without cleaning, probably gave fairly accurate results.

The spots occurring on the plates after immersion in the hot solutions containing potassium dichromate were invariably of black or brownish-black colour. Those in solutions containing larger amounts of sodium phosphate were of the characteristic dull green colour.

ACTION OF SOLUTIONS OF CHLORIDES AND SULPHATES UPON IRON AND STEEL AT ROOM TEMPERATURE IN THE PRESENCE OF POTASSIUM DICHROMATE.

The following results show the effect of various amounts of potassium dichromate upon the rate of corrosion of iron and steel when introduced into solutions of different concentrations of chlorides and sulphates. In some cases the addition of dichromate prevented corrosion completely, especially with the more concentrated solutions of this substance, while in others its inhibiting character was very striking.

When placed in solutions free from dichromate, the low carbon steel showed a slightly greater tendency toward corrosion than did the commercially pure iron.

Test-plates of the low carbon steel and the commercially pure iron were placed in distilled water and subjected to the same treatment as accorded to the samples in the various solutions. The results thus obtained were utilized as a standard in computing the relative corrosion. This was determined by taking the loss in weight of the samples in the distilled water and dividing into the loss in weight by the test-plates in the solutions.

$$\text{Relative corrosion} = \frac{\text{Loss in weight in X solution.}}{\text{Loss in weight in distilled water.}}$$

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table I.—Action of Water.

No.	Original Weight.	Loss in Weight.	Remarks.
A	18.4197	0.1995	Badly corroded.
B	19.6435	0.2021	" "
C	16.6748	0.1969	" "
D	19.2308	0.1956	" "

Table II.—Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
81	1/1000	19.8732	0.0010	0	Slight corrosion on edges.
82	1/100	18.8425	0.0004*	0	No corrosion.
83	1/10	18.9613	0.0000	0	Metal bright.
84	1/5	18.0086	0.0001	0	" "

LOW CARBON STEEL. ROOM TEMPERATURE.

Table III.—Action of Water.

No.	Original Weight.	Loss in Weight.	Remarks.
A	7.3013	0.2232	Badly corroded.
B	7.8240	0.2113	" "
C	8.0327	0.2135	" "
D	7.9241	0.2203	" "

* Gain in weight.

Table IV.—Potassium Dichromate.

No.	Normality.	Original Weight	Loss in Weight.	Relative Cor'sion.	Remarks.
329	1/1000	8.4997	0.0005	0	Slight corrosion.
330	1/100	8.1320	0.0001	0	No corrosion.
331	1/10	8.1652	0.0003	0	Metal bright.
332	1/5	8.0663	0.0004	0	" "

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table V.—Sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
1	1/1000	18.2439	0.2298	115	Covered with rust.
2	1/100	19.8746	0.2203	110	" " "
3	1/10	20.1324	0.1897	93	" " "
4	N	20.4938	0.1204	59	" " "

Table VI.—Sodium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
5	1/1000	20.4132	0.2133	105	Covered with rust.
6	1/100	19.5453	0.2175	107	" " "
8	1/10	19.7463	0.2556	128	" " "
8	N	19.7077	0.1561	78	" " "

Table VII.—Magnesium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
9	1/1000	19.0452	0.2028	103	Covered with rust.
10	1/100	18.7993	0.2468	122	" " "
11	1/10	20.4995	0.1686	83	" " "
12	N	19.5231	0.1214	55	" " "

Table VIII.—Magnesium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
13	1/1000	19.8018	0.2283	113	Covered with rust.
14	1/100	20.3402	0.1828	90	" " "
15	1/10	20.2853	0.1258	62	" " "
16	N	19.2753	0.1176	58	" " "

LOW CARBON STEEL. ROOM TEMPERATURE.

Table IX.—Sodium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
249	1/1000	8.0917	0.2597	118	Covered with rust.
250	1/100	7.8634	0.2267	104	" " "
251	1/10	7.4396	0.1648	75	" " "
252	N	7.5003	0.1124	52	" " "

Table X.—Sodium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
253	1/1000	7.9239	0.2285	105	Covered with rust.
254	1/100	7.9880	0.2332	108	" " "
255	1/10	7.7302	0.2505	115	" " "
256	N	7.4951	0.1786	82	" " "

Table XI.—Magnesium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
257	1/1000	7.0276	0.2640	122	Covered with rust.
258	1/100	7.8348	0.2832	130	" " "
259	1/10	8.0051	0.1562	72	" " "
260	N	8.1704	0.1137	52	" " "

Table XII.—Magnesium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
261	1/1000	8.1027	0.2529	116	Covered with rust.
262	1/100	7.6020	0.2670	122	" " "
263	1/10	7.9926	0.2218	102	" " "
264	N	7.4304	0.1893	87	" " "

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table XIII.—Sodium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
17	1/1000	17.7931	0.0190	10	Corrosion around edges.
18	1/100	17.4386	0.0165	8	" " "
19	1/10	18.8439	0.0077	4	Few small rust spots.
20	N	17.5677	0.0132	7	" large " "

Table XIV.—Sodium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
21	1/1000	18.8235	0.0000	0	No rust.
22	1/100	17.9828	0.0005	0	" "
23	1/10	17.8812	0.0021	1	Few minute rust spots.
24	N	18.5079	0.0046	2	Rust around edges.

Table XV.—Sodium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
25	1/1000	17.7866	0.0001 [1]	0	Metal bright. No rust.
26	1/100	18.6974	0.0005 [1]	0	" " " "
27	1/10	18.5133	0.0006 [1]	0	Several black spots.
28	N	18.1652	0.0043	2	" " "

[1] Gain in weight.

Table XVI.—Sodium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
29	1/1000	18.6887	0.0001 [1]	0	Metal bright. No rust.
30	1/100	18.9888	0.0002 [1]	0	" " " "
31	1/10	18.4944	0.0003	0	Several minute spots.
32	N	18.5613	0.0045	2	Many minute rust spots.

LOW CARBON STEEL. ROOM TEMPERATURE.

Table XVII.—Sodium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
265	1/1000	8.0241	0.0112	5	Few rust spots.
266	1/100	7.0198	0.0225	10	" " "
267	1/10	8.4727	0.0090	4	" " "
268	N	7.9607	0.0092	4	" " "

Table XVIII.—Sodium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight	Loss in Weight.	Relative Cor'sion.	Remarks.
269	1/1000	6.7617	0.0001	0	No corrosion.
270	1/100	6.7436	0.0033	2	Few rust spots.
271	1/10	7.7283	0.0032	2	" " "
272	N	7.9914	0.0045	2	" " "

Table XIX.—Sodium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
272	1/1000	6.6671	0.0001	0	No corrosion.
274	1/100	6.2877	0.0000	0	" "
275	1/10	6.7019	0.0067	3	Few rust spots.
276	N	8.4086	0.0049	2	" " "

Table XX.—Sodium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
277	1/1000	6.9826	0.0003	0	No corrosion.
278	1/100	6.9373	0.0001	0	" "
279	1/10	6.9747	0.0010 [1]	0	" "
280	N	6.7125	0.0027	1	Few rust spots.

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table XXI.—Magnesium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
33	1/1000	18.6374	0.0011	1	Slight rusting on edge
34	1/100	17.7247	0.0031	2	" " " "
35	1/10	18.5333	0.0080	4	Many small rust spots.
36	N	18.8740	0.0119	6	" " " "

[1] Gain in weight.

Table XXII.—Magnesium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
37	1/1000	18.8471	0.0002 [1]	0	No rust.
38	1/100	18.7850	0.0022	1	Several black spots.
49	1/10	18.2635	0.0107	5	Many small spots.
40	N	18.1070	0.0264	13	Covered with spots.

Table XXIII.—Magnesium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
41	1/1000	18.6751	0.0000	0	Metal bright.
42	1/100	18.7850	0.0003 [1]	0	" "
43	1/10	18.7790	0.0008	1	Minute rust spots.
44	N	19.8571	0.0280	14	Covered with spots.

Table XXIV.—Magnesium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Weight. Original	Weight. Loss in	Cor'sion. Relative	Remarks.
45	1/1000	19.1785	0.0000	0	Metal bright.
46	1/100	19.5526	0.0003 [1]	0	" "
47	1/10	19.9281	0.0010	1	Few minute rust spots.
48	N	18.2517	0.0238	12	Covered with rust spots.

LOW CARBON STEEL. ROOM TEMPERATURE.

Table XXV.—Magnesium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
281	1/1000	6.9384	0.0038	2	Few spots over surface.
282	1/100	7.0442	0.0127	6	Many small spots.
283	1/10	7.6038	0.0073	4	Few small rust spots.
284	N	7.6373	0.0124	6	Many small spots.

Table XXVI.—Magnesium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
285	1/1000	7.7890	0.0000	0	No corrosion.
286	1/100	7.7853	0.0050	3	Few rust spots.
287	1/10	7.9115	0.0094	5	" " "
288	N	7.6104	0.0218	11	Many rust spots.

Table XXVII.—Magnesium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
289	1/1000	7.5233	0.0002	0	No corrosion.
290	1/100	7.8860	0.0001	0	" "
291	1/10	8.1318	0.0004	0	" "
292	N	7.6104	0.0210	11	Covered with spots.

[1] Gain in weight.

Table XXVIII.—Magnesium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
293	1/1000	7.4765	0.0002	0	Metal bright.
294	1/100	7.2624	0.0002	0	" "
295	1/10	8.1285	0.0007	0	No corrosion.
296	N	8.3027	0.0241	12	Covered with rusty spots.

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table XXIX.—Saturated Solution of Calcium Sulphate (20° C.).

No.	Normality.[1]	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
85	1/1000	18.3412	0.0098	5	Several large streaks.
86	1/100	18.0028	0.0007[2]	0	Black spots.
87	1/10	18.7949	0.0003[2]	0	No corrosion.
88	1/5	18.7370	0.0002[2]	0	" "

LOW CARBON STEEL. ROOM TEMPERATURE.

Table XXX.—Saturated Solution of Calcium Sulphate (20° C.).

No.	Normality.[1]	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
365	1/1000	8.0091	0.0088	4	Minute spots.
366	1/100	7.7364	0.0001	0	No corrosion.
367	1/10	7.1023	0.0004	0	" "
368	1/5	7.4972	0.0005	0	" "

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table XXXI.—Sodium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
49	1/1000	18.2921	0.0452	23	Covered with rust.
50	1/100	18.3231	0.0100	5	Narrow long black streaks.
51	1/10	18.5411	0.0122	6	" " " "
52	N	18.2830	0.0173	9	Covered with thin layer of rust.

Table XXXII.—Sodium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
53	1/1000	17.3569	0.0004[1]	0	No corrosion.
54	1/100	17.7729	0.0021	1	Several rust spots.
55	1/10	18.8033	0.0183	9	Covered with thin layer of rust.
56	N	18.1411	0.0329	17	Covered with rust spots.

[1] Normality of potassium dichromate.
[2] Gain in weight.

Table XXXIII.—Sodium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
57	1/1000	17.9824	0.0004 [1]	0	No corrosion.
58	1/100	18.9423	0.0003 [1]	0	" "
59	1/10	18.8458	1.0307	15	Covered with layer of rust.
60	N	18.7504	0.0633	32	" " " "

Table XXXIV.—Sodium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
61	1/1000	17.5235	0.0001 [1]	0	Metal bright.
62	1/100	18.4591	0.0004 [1]	0	" "
63	1/10	17.9659	0.0423	21	Many small rust spots.
64	N	18.2212	0.0530	27	Badly corroded.

LOW CARBON STEEL. ROOM TEMPERATURE.

Table XXXV.—Sodium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
297	1/1000	8.0472	0.0374	19	Rust spots in streaks.
298	1/100	8.2619	0.0185	9	Many rust spots.
299	1/10	7.7362	0.0156	8	Large rust spots.
300	N	8.5746	0.0190	10	" " "

Table XXXVI.—Sodium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
301	1/1000	8.6156	0.0001	0	No corrosion.
302	1/100	7.5995	0.0002	0	Several minute spots.
303	1/10	8.5122	0.0174	9	Many small rust spots.
304	N	8.1990	0.0375	19	Covered with large rust spots.

Table XXXVII.—Sodium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
305	1/1000	8.4199	0.0007	0	No corrosion.
306	1/100	8.5453	0.0016	1	Few minute rust spots.
307	1/10	7.9314	0.0336	17	Covered with small spots.
308	N	8.7001	0.0652	33	" " " "

Table XXXVIII.—Sodium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
309	1/1000	8.0314	0.0005	0	No corrosion.
310	1/100	6.6100	0.0035	2	Few minute spots.
311	1/10	7.5867	0.0409	20	Many large rust spots.
312	N	8.1445	0.0515	26	" " " "

[1] Gain in weight.

COMMERCIALLY PURE IRON. ROOM TEMPERATURE.

Table XXXIX.—Magnesium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
65	1/1000	17.5235	0.0018	1	Corrosion on edges.
66	1/100	18.4563	0.0024	1	Few minute rust spots.
67	1/10	18.6983	0.0164	8	Covered with minute rust spots.
68	N	18.8969	0.0128	6	Many small rust spots.

Table XL.—Magnesium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
69	1/1000	17.0475	0.0002	0	Several minute spots.
70	1/100	17.3322	0.0009 [1]	0	No corrosion.
71	1/10	17.3590	0.0151	8	Covered with thin layer rust.
72	N	17.8621	0.0246	12	" " " " "

Table XLI.—Magnesium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
73	1/1000	19.5877	0.0004 [1]	0	Metal bright.
74	1/100	18.1777	0.0003 [1]	0	" "
75	1/10	18.0645	0.0209	10	Covered with small lumpy rust spots.
76	N	18.1682	0.0528	26	" " " "

Table XLII.—Magnesium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
77	1/1000	18.9682	0.0004 [1]	0	Metal bright.
78	1/100	17.4384	0.0002 [1]	0	" "
19	1/10	18.3128	0.0212	11	Covered with small lumpy spots.
80	N	17.9440	0.0540	27	" " " "

LOW CARBON STEEL. ROOM TEMPERATURE.

Table XLIII.—Magnesium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
313	1/1000	8.7930	0.0020	1	Few rust spots.
314	1/100	8.4156	0.0038	2	" " "
315	1/10	8.5263	0.0143	7	Rust around edges.
316	N	7.4669	0.0160	8	Many minute spots.

[1] Gain in weight.

Table XLIV.—Magnesium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
317	1/1000	8.7930	0.0020	1	Minute spots.
318	1/100	8 3371	0.0057	3	Several large black spots.
319	1/10	7.7715	0.1042	7	Covered with minute spots.
320	N	8.2331	0.0550	27	" " " "

Table XLV.—Magnesium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
321	1/1000	7.7367	0.0004	0	No corrosion.
322	1/100	8.0481	0.0004	0	" "
323	1/10	8.0177	0.0193	10	Covered with spots.
324	N	8.5306	0.0632	31	Badly corroded.

Table XLVI.—Magnesium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
325	1/1000	7.9113	0.0003	0	No corrosion.
326	1/100	8.1286	0.0001	0	" "
327	1/10	7.9591	0.0259	13	Covered with rust spots.
328	N	8.3227	0.0756	38	Badly corroded.

SUMMARY OF RESULTS. ROOM TEMPERATURE.

Solutions of Sodium Sulphate and Potassium Dichromate.

1. The differences in chemical composition and physical properties had no influence upon the rate of corrosion.

2. Only the solutions which contained very dilute amounts of potassium dichromate showed any marked corrosion.

3. N/10 and N/5 potassium dichromate rendered the iron and steel passive in the more dilute solutions of the sodium sulphate.[1]

4. In all other cases the potassium dichromate decidedly inhibited corrosion.

Solutions of Magnesium Sulphate and Potassium Dichromate.

1. The differences in chemical composition and physical properties of the iron and steel had no influence upon the rate of corrosion.

2. Tenth normal and normal solutions of magnesium sulphate containing potassium dichromate in all proportions used, were covered with rust spots of varying sizes. While this was generally true in the case of sodium sulphate solutions, the rate of corrosion with the magnesium sulphate solutions was much greater.

[1] The passivification of the test-plates was determined by dipping them into nitric acid of 1.20 specific gravity.

3. N/10 and N/5 potassium dichromate passivified the test-plates of both iron and steel in N/100 magnesium sulphate. This was also true with N/5 potassium dichromate in N/100 magnesium sulphate. With the latter solution containing N/10 potassium dichromate, the passive state was demonstrated twice with four test-plates of iron and twice with three test-plates of the steel. To determine the passive state of the iron and steel, other plates than those used to secure the loss in weight were run under identical conditions. At the end of two weeks they were washed carefully, and then immersed in the nitric acid of 1.20 sp. gr.

4. In all cases potassium dichromate inhibited corrosion to a marked extent.

Saturated Solution of Calcium Sulphate (20° C.) and Potassium Dichromate.

1. With the exception of N/1000 potassium dichromate, the addition of this salt to the saturated solution of calcium sulphate produced results similar to those obtained in solutions containing only the dichromate.

Solutions of Sodium Chloride and Potassium Dichromate.

1. There was no difference in the behavior of the iron and steel.

2. The most peculiar action was obtained with N/1000 solution of both the sodium chloride and potassium dichromate. With this solution the rate of corrosion was many times higher than that obtained with magnesium chloride or with the sulphate solutions. With the iron, four tests gave a loss in weight of 0.0452, 0.0397, 0.0190, and 0.0432 gram.

3. The passive state was demonstrated in many cases with N/1000 and N/100 sodium chloride containing N/10 and N/5 potassium dichromate.

4. The inhibiting action of the dichromate is less in the sodium chloride solutions than in the corresponding sulphate solutions.

Solutions of Magnesium Chloride and Potassium Dichromate.

1. The behavior of the iron and steel appears to be the same in many cases.

2. Test-plates were passivified in N/1000 and N/100 solutions of the chloride with N/10 and N/5 potassium dichromate.

3. In the more concentrated solutions of the chloride, an increase in either salt produced an increase in corrosion.

4. The inhibiting action of the potassium dichromate is less than in the corresponding sulphate solutions.

5. The action of many of the magnesium chloride solutions were similar to those of sodium chloride. Normal solutions of the former, however, were exceptions, corrosion being much greater.

ACTION OF SOLUTIONS OF CHLORIDES AND SULPHATES UPON IRON AND STEEL AT THE TEMPERATURE OF BOILING WATER IN THE PRESENCE OF POTASSIUM DICHROMATE.

In the tests run at room temperature potassium dichromate reduced corrosion to a marked extent in every case, in some instances preventing all chemical action upon the iron and steel. Thus tanks used for storing non-potable waters at atmospheric temperatures could be well preserved by the addition of small quantities of potassium dichromate. However, with waters in boilers the addition of this compound will, in many cases, serve as a stimulative agent rather than as a preventive for corrosion. This will be seen by studying the data obtained when the iron and steel were placed in solutions free from dichromate at boiling temperature for two weeks and comparing them with the results from those boiled in solutions in which this salt was present. In many of the solutions the presence of the dichromate was occasioned by a slight increase in corrosion. This was especially true in the chloride solutions. In fact, from the general appearances of the test-plates, this increase in corrosion seemed greater than that actually represented by the following figures.

Plates of the iron and steel were introduced into distilled water and subjected to the same treatment as accorded to the samples in the various solutions. At the end of two weeks the plates were removed, dried, and weighed. The plates were all slightly tarnished. The gain in weight of the plates served as a standard for calculating the relative corrosion.

The test-plates immersed in the salt solutions free from dichromate corroded to a certain extent, a small brown precipitate settling on the bottom of the containing vessel. It was thus impossible to weigh the plates directly and determine the rate of corrosion by gain in weight. The plates, however, were very easily cleaned with ammonium citrate and the loss in weight determined. The equivalent amount of ferric oxide represented by the loss in weight was calculated. While this does not accurately represent the actual amount of corrosive matter produced it is fairly approximate, so that it can be reasonably compared with the data obtained from plates where cleaning was impossible.

N/5 dichromate produced a decrease in the rate of corrosion in nearly every case. In some instances, especially with solutions of sodium sulphate containing N/10 dichromate, there is a decided increase in corrosion, while in others the dichromate appears to have little or no effect. In general the addition of dichromate to boiler waters would be of no practical use, as an alteration in the concentrations of the salts would produce a difference in action. This would be especially true if chlorides were present. Under such circumstances the effect of the sulphates would be acted upon by the chlorides and the final result would be a stimulation of corrosion.

The presence of dichromate in solutions of the chlorides caused a decided increase in the rate of corrosion, the magnesium chloride being more violent in its behavior than the sodium chloride. Chemical interaction

undoubtedly takes place between the chlorides, potassium dichromate, and water, with the production of small amounts of hydrochloric acid, thus causing the great increase in corrosive action. Friend[1] has suggested the following chemical equation to show the production of the hydrochloric acid:

$$2NaCl+K_2Cr_2O_7+H_2O \longrightarrow Na_2CrO_4+K_2CrO_4+2HCl$$

Because of experimental difficulties the results reported for the action of the stronger solutions of the chlorides with N/10 and N/5 dichromate upon the iron and steel are low:

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Table XLVII.—Action of Water.

No.	Original Weight.	Gain in Weight.	Remarks.
A	19.1064	0.0055	Tarnished.
B	18.8200	0.0048	"
C	18.8349	0.0043	"
D	19.1126	0.0063	"
E	18.7442	0.0057	"

Table XLVIII.—Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
189	1/1000	19.1515	0.0023	--	Tarnished
190	1/100	19.7182	0.0015	--	Slightly tarnished.
191	1/10	18.2635	0.0013	--	" "
192	1/5	19.6910	0.0010	--	" "

LOW CARBON STEEL. TEMPERATURE OF BOILING WATER.

Table XLXIX.—Action of Water.

No.	Original Weight.	Gain in Weight.	Remarks.
A	7.0429	0.0074	Minute spots.
B	7.0774	0.0074	" "
C	7.4627	0.0081	" "
D	6.9830	0.0090	" "

Table L.—Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
445	1/1000	6.2030	0.0017	--	Slightly tarnished.
446	1/100	7.4011	0.0007	--	" "
447	1/10	6.6794	0.0015	--	" "
448	1/5	7.0553	0.0015	--	" "

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Table LI.—Sodium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
193	1/1000	19.2936	0.0039	0.0056	----
194	1/100	18.6913	0.0043	0.0061	----
195	1/10	18.4841	0.0057	0.0081	----
196	N	16.6731	0.0062	0.0089	----

Table LII.—Magnesium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
197	1/1000	17.4416	0.0043	0.0061	----
198	1/100	19.6567	0.0049	0.0070	----
199	1/10	18.6475	0.0062	0.0089	----
200	N	18.9933	0.0071	0.0101	----

Table LIII.—Sodium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
201	1/1000	18.8491	0.0043	0.0061	----
202	1/100	16.3931	0.0051	0.0073	----
203	1/10	17.9781	0.0063	0.0090	----
204	N	16.9963	0.0054	0.0077	----

Table LIV.—Magnesium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
205	1/1000	17.7218	0.0049	0.0070	----
206	1/100	18.4160	0.0058	0.0083	----
207	1/10	18.5508	0.0096	0.0137	----
208	N	17.0679	0.0107	0.0153	----

LOW CARBON STEEL. TEMPERATURE OF BOILING WATER.

Table LV.—Sodium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
377	1/1000	6.5609	0.0063	0.0090	----
378	1/100	6.0070	0.0061	0.0088	----
379	1/10	7.6734	0.0066	0.0094	----
380	N	7.1523	0.0067	0.0096	----

Table LVI.—Magnesium Sulphate.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
381	1/1000	6.3835	0.0058	0.0083	----
382	1/100	6.7226	0.0058	0.0083	----
383	1/10	6.8952	0.0063	0.0090	----
384	N	7.2419	0.0071	0.0100	----

Table LVII.—Sodium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
385	1/1000	6.3420	0.0054	0.0077	----
386	1/100	7.4483	0.0062	0.0089	----
387	1/10	7.2679	0.0068	0.0097	----
388	N	6.7082	0.0059	0.0084	----

Table LVIII.—Magnesium Chloride.

No.	Normality.	Original Weight.	Loss in Weight.	Loss as Ferric Oxide.	Remarks.
389	1/1000	6.7509	0.0062	0.0089	----
390	1/100	7.1248	0.0068	0.0097	----
391	1/10	7.5381	0.0092	0.0131	----
392	N	7.0032	0.0118	0.0169	----

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Table LIX.—Sodium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
121	1/1000	18.2543	0.0081	155	Few streaks and spots.
122	1/100	17.9236	0.0052	100	" " " "
123	1/10	18.0497	0.0042	79	Several spots.
124	N	18.5067	0.0057	107	Few spots.

Table LX.—Sodium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
125	1/1000	18.2348	0.0038	71	No corrosion. Tarnished.
126	1/100	19.5568	0.0049	92	Few spots.
127	1/10	18.7812	0.0060	113	Streaks and spots.
128	N	18.0550	0.0076	143	" " "

Table LXI.—Sodium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
129	1/1000	18.9583	0.0036	68	No corrosion.
130	1/100	18.7540	0.0086	162	Well tarnished.
131	1/10	19.6902	0.0158	299	Few rust spots.
132	N	18.8220	0.0077	145	Few streaks.

Table LXII.—Sodium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
133	1/1000	18.1663	0.0033	62	No corrosion.
134	1/100	19.1555	0.0033	62	" "
135	1/10	18.0014	0.0120	226	Few spots and streaks.
136	N	18.0851	0.0124	234	" " " "

LOW CARBON STEEL. TEMPERATURE OF BOILING WATER.

Table LXIII.—Sodium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
393	1/1000	7.8221	0.0067	84	Few streaks and spots.
394	1/100	8.7803	0.0073	91	" " " "
395	1/10	9.1039	0.0095	119	Many minute spots.
396	N	8.9027	0.0086	108	Few spots and streaks.

Table LXIV.—Sodium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
397	1/1000	8.2508	0.0057	71	Few spots.
398	1/100	7.5331	0.0058	73	" "
399	1/10	8.2940	0.0098	123	Streaks and spots.
400	N	8.7572	0.0095	119	" " "

Table LXV.—Sodium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
401	1/1000	8.9566	0.0037	46	No corrosion.
402	1/100	9.1438	0.0091	114	" " Tarnished
403	1/10	9.0236	0.0124	155	Few spots and streaks.
404	N	9.0028	0.0119	149	" " " "

Table LXVI.—Sodium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
405	1/1000	9.1142	0.0043	54	No corrosion. Tarnished.
406	1/100	9.2546	0.0032	40	" " "
407	1/10	8.7928	0.0114	143	Few rust spots.
408	N	8.2371	0.0097	121	" " "

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Table LXVII. Magnesium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight	Gain in Weight.	Relative Cor'sion.	Remarks.
137	1/1000	19.1782	0.0048	91	Few spots.
138	1/100	19.2714	0.0101	191	Black spots and streaks.
139	1/10	18.2537	0.0077	145	Black streaks.
140	N	18.5238	0.0110	208	" "

Table LXVIII.—Magnesium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
141	1/1000	19.1782	0.0046	87	Dull in color.
142	1/100	18.7740	0.0073	138	Spots over surface.
143	1/10	18.7936	0.0097	183	" " "
144	N	18.9597	0.0126	238	" " "

Table LXIX.—Magnesium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
145	1/1000	17.1741	0.0006	11	Slightly tarnished.
146	1/100	17.8488	0.0013	23	" "
147	1/10	18.3274	0.0086	162	Few small spots.
148	N	18.3712	0.0106	200	" " "

Table LXX.—Magnesium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
149	1/1000	18.5256	0.0003	6	No corrosion.
150	1/100	18.1176	0.0011	21	Slightly tarnished.
151	1/10	19.6333	0.0065	123	Spots and streaks.
152	N	18.8247	0.0082	151	" " "

LOW CARBON STEEL. TEMPERATURE OF BOILING WATER.

Table LXXI.—Magnesium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
409	1/1000	8.3184	0.0037	46	Black spots and streaks.
410	1/100	7.0408	0.0160	200	Many spots.
411	1/10	7.9015	0.0097	121	Spots and streaks.
412	N	7.1787	0.0115	144	" " "

Table LXXII.—Magnesium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
413	1/1000	8.1879	0.0042	53	Few black spots.
414	1/100	9.2314	0.0118	148	Many small spots.
415	1/10	7.9020	0.0088	110	Spots over surface.
416	N	7.1787	0.0108	145	Many small spots.

Table LXXIII.—Magnesium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
417	1/1000	7.8221	0.0010	13	Slightly tarnished.
418	1/100	8.0716	0.0013	16	" "
419	1/10	8.8831	0.0085	106	Few spots over surface.
420	N	7.8375	0.0100	125	Many small spots.

Table LXXIV.—Magnesium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
421	1/1000	7.2037	0.0014	18	Slightly tarnished.
422	1/100	9.1524	0.0009	11	" "
423	1/10	8.2165	0.0057	71	Few small spots.
424	N	8.5532	0.0095	119	Spots and streaks.

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Table LXXV.—Sodium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
153	1/1000	18.1790	0.0075	141	Few black spots.
154	1/100	18.6186	0.0069	130	" " "
155	1/10	18.2633	0.0066	124	" " "
156	N	18.9162	0.0062	117	" " "

Table LXXVI.—Sodium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
157	1/1000	18.9220	0.0120	226	Few black spots.
158	1/100	18.1262	0.0208	392	Spots over surface.
159	1/10	17.6083	0.0267	504	Many small spots.
160	N	17.2738	0.0210	396	" " "

Table LXXVII.—Sodium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
161	1/1000	18.2339	0.0011	20	Tarnished slightly.
162	1/100	19.3364	0.0048	91	Well tarnished.
163	1/10	18.2891	0.0282	532	Many small spots.
164	N	18.7213	0.0447	843	Covered with rust.

Table LXXVIII.—Sodium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
165	1/1000	19.2181	0.0018	34	Slightly tarnished.
166	1/100	19.7539	0.0078	147	Few spots.
167	1/10	18.9736	0.0262	494	Many small spots.
168	N	19.3316	0.0453	855	Covered with rust.

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Table LXXIX.—Sodium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
425	1/1000	8.6269	0.0065	81	Few small spots.
426	1/100	7.4392	0.0095	119	Many small spots.
427	1/10	7.7890	0.0082	102	Several streaks and spots.
428	N	7.5234	0.0052	65	" " " "

Table LXXX.—Sodium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
429	1/1000	8.8366	0.0139	174	Many minute spots.
430	1/100	7.6972	0.0134	168	" " "
431	1/10	8.1314	0.0167	209	Streaks and spots.
432	N	8.1278	0.0190	238	" " "

Table LXXXI.—Sodium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
433	1/1000	7.6622	0.0013	16	Slightly tarnished.
434	1/100	7.6972	0.0052	65	Few spots.
435	1/10	7.8208	0.0254	318	Many minute spots.
436	N	8.7049	0.0434	543	Badly corroded.

Table LXXXII.—Sodium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
437	1/1000	7.5060	0.0014	18	Slightly tarnished.
438	1/100	7.3744	0.0093	116	Few minute spots.
439	1/10	7.6206	0.0254	318	Covered with spots.
440	N	7.7049	0.0468	585	Badly corroded.

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Table LXXXIII.—Magnesium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
169	1/1000	18.6425	0.0091	173	Spots and streaks.
170	1/100	19.0886	0.0116	219	Many small spots.
171	1/10	19.7181	0.0132	249	Streaks and spots.
172	N	18.0293	0.0231	436	" " "

Table LXXXIV.—Magnesium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
173	1/1000	19.1877	0.0057	108	Few minute spots.
174	1/100	18.9242	0.0149	281	Many spots.
175	1/10	18.6621	0.0229	432	Badly corroded.
176	N	18.4985	0.0321	606	" "

LXXXV.—Magnesium Chloride with N/10 Potassium-Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
177	1/1000	17.9358	0.0010	19	Tarnished.
178	1/100	19.4608	0.0014	26	Well tarnished.
179	1/10	18.3315	0.0289	545	Many spots and streaks.
180	N	18.9670	0.0479	903	Badly corroded.

Table LXXXVI.—Magnesium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
181	1/1000	18.4936	0.0011	20	Slightly tarnished.
182	1/100	19.4126	0.0011	20	" "
183	1/10	18.3315	0.0321	606	Many spots and streaks.
184	N	19.1092	0.0744	140	Badly corroded.

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Table LXXXVII.—Magnesium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
465	1/1000	7.2108	0.0122	153	Many small spots.
466	1/100	6.9734	0.0122	153	Streaks and spots.
467	1/10	7.0399	0.0180	225	" " "
468	N	8.0032	0.0227	284	Many spots and streaks.

Table LXXXVIII.—Magnesium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor sion.	Remarks.
469	1/1000	6.8296	0.0045	56	Few spots.
470	1/100	7.1818	0.0163	204	Many minute spots.
471	1/10	7.1590	0.0193	241	Streaks and spots.
472	N	7.9684	0.0237	284	Covered with rust.

Table LXXXIX.—Magnesium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
473	1/1000	7.3246	0.0020	25	Slightly tarnished.
474	1/100	7.7206	0.0015	19	" "
475	1/10	8.0416	0.0282	353	Covered with spots.
476	N	7.3858	0.0459	574	Badly corroded.

Table XC.—Magnesium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
477	1/1000	7.2677	0.0005	6	Slightly tarnished.
478	1/100	6.7138	0.0019	24	Tarnished.
479	1/10	8.3392	0.0419	524	Badly corroded.
480	N	7.3858	0.0879	1099	" "

SUMMARY OF RESULTS. (TEMPERATURE OF BOILING WATER.)

Solutions of Sodium Sulphate with Potassium Dichromate.

1. With very dilute solutions of the sulphate the addition of dichromate causes a slight inhibition in corrosion.

2. In the more concentrated solution the addition of dichromate stimulates corrosion.

3. In many cases the corrosion of the test-plates appeared to be greater in comparison with those in solutions free from dichromate than is actually represented by the gain in weight.

4. Generally the low carbon steel was more easily attacked than the commercially pure iron.

Solutions of Magnesium Sulphate with Potassium Dichromate.

1. With the exception of N/1000 magnesium sulphate the addition of dichromate in small amounts stimulated corrosion.

2. N/10 and N/5 dichromate inhibited corrosion in varying degrees.

3. Generally the low carbon steel was more easily attacked than the commercially pure iron.

4. The action of the magnesium sulphate solutions were less than those of sodium sulphate.

Solutions of Sodium Chloride with Potassium Dichromate.

1. N/1000 dichromate had practically no effect upon the corrosion of the plates, although there was a general tendency towards inhibition.

2. N/100 dichromate stimulated corrosion in every case.

3. With the more dilute solutions of sodium chloride, N/10 and N/5 dichromate inhibited corrosion.

4. N/10 and N/5 dichromate in the more concentrated solutions of sodium chloride stimulated corrosion to a marked extent.

5. Commercially pure iron showed a slightly greater increase in the rate of corrosion than did the low carbon steel.

6. Sodium chloride and potassium dichromate interacted with water to produce traces of hydrochloric acid.

Solutions of Magnesium Chloride with Potassium Dichromate.

1. In all cases the action of these solutions upon the iron and steel was greater than the corresponding solutions of sodium chloride.

2. N/10 and N/5 dichromate in the dilute solutions of magnesium chloride inhibited corrosion.

3. In all other solutions increase in either the dichromate or the chloride produced conditions that strongly stimulated corrosion.

4. Magnesium chloride and potassium dichromate interact with water to produce hydrochloric acid.

ACTION OF DI-SODIUM PHOSPHATE IN THE PRESENCE OF SODIUM SULPHATE AND SODIUM CHLORIDE.

When an iron strip is made the anode in an electric circuit and placed in a solution of di-sodium phosphate, it is passivified. It has been shown by Heyn and Bauer that iron placed in this solution will not corrode as readily as in solutions of commoner salts, and that a point or "limiting concentration" is reached where all corrosive action ceases. As this phosphate is used to a certain extent as a boiler water softener, it was decided to study its effect in solutions of sodium chloride and sodium sulphate upon the iron and steel used in other experiments. The tests were conducted in the same manner as previously described and the data obtained follows:

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Table XCI.—Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
241	1/1000	18.7146	0.1494	75	Badly corroded.
242	1/100	17.1147	0.0190	9	Green and brown rust.
243	1/10	18.4924	0.0005 [1]	0	No corrosion.
244	N	18.0340	0.0001 [1]	0	" "

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Table XCII.—Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
369	1/1000	6.4191	0.1339	61	Badly corroded.
370	1/100	6.9566	0.0232	10	Greenish brown rust.
371	1/10	7.3431	0.0004 [1]	0	No corrosion.
372	N	6.8778	0.0000	0	" "

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Table XCIII.—Sodium Sulphate with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
89	1/1000	17.6301	0.1893	95	Badly corroded.
90	1/100	17.3585	0.1792	85	" "
91	1/10	18.3143	0.1850	93	" "
92	N	18.9224	0.1109	55	" "

Table XCIV.—Sodium Sulphate with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks
93	1/1000	18.7378	0.0489	24	Covered with a light brown layer mottled with greenish streaks.
94	1/100	19.5230	0.0505	25	
	1/10	19.6386	0.0613	13	
	N	19.3583	0.0861	33	Badly corroded.

[1] Gain in weight.

Table XCV.—Sodium Sulphate with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
97	1/1000	19.2083	0.0002 [1]	0	No corrosion.
98	1/100	18.5526	0.0061	3	Small lumpy green spots.
99	1/10	18.9841	0.0195	10	Large " " "
100	N	19.6082	0.0309	15	Covered with brown rust.

Table XCVI.—Sodium Sulphate with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
101	1/1000	20.0196	0.0004 [1]	0	No corrosion.
102	1/100	19.3779	0.0000	0	" "
103	1/10	19.9065	0.0032	1	Small green festoons on edge.
104	N	18.7244	0.0266	13	Greenish-brown deposits.

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Table XCVII.—Sodium Sulphate with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
209	1/1000	7.2392	0.2221	111	Badly corroded.
210	1/100	6.7040	0.1597	80	" "
211	1/10	7.7197	0.1862	93	" "
212	N	7.2695	0.1428	71	" "

Table XCVIII.—Sodium Sulphate with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
213	1/1000	7.0472	0.0285	14	Few small spots.
214	1/100	7.7363	0.0304	15	Brown spots and streaks.
215	1/10	7.5623	0.0733	36	Badly corroded.
216	N	7.0303	0.0842	42	" "

Table XCIX.—Sodium Sulphate with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
217	1/1000	7.7705	0.0003 [1]	0	No corrosion.
218	1/100	7.3620	0.0182	9	Few minute green spots.
219	1/10	6.6200	0.0183	9	" " " "
220	N	7.7727	0.0427	21	Well corroded.

Table C.—Sodium Sulphate with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
221	1/1000	7.3201	0.0001 [1]	0	No corrosion.
222	1/100	7.6792	0.0002 [1]	0	" "
223	1/10	7.5185	0.0093	5	Few minute green spots
224	N	6.9973	0.0399	20	" large " "

[1] Gain in weight.

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Table CI.—Sodium Chloride with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
105	1/1000	18.1240	0.1424	71	Badly corroded.
106	1/100	18.9513	0.1376	69	" "
107	1/10	19.0994	0.1260	63	" "
108	N	18.0001	0.1336	67	" "

Table CII.—Sodium Chloride with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
109	1/1000	18.2028	0.0917	46	Badly corroded.
110	1/100	19.1043	0.0962	48	" "
111	1/10	18.7914	0.0208	10	Green streaks.
112	N	18.9768	0.0138	6	" "

Table CIII.—Sodium Chloride with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
113	1/1000	18.8776	0.0003 [1]	0	No corrosion.
114	1/100	18.9418	0.0063	3	Few green spots.
115	1/10	17.2943	0.0350	17	Large green spots.
116	N	19.1335	0.0243	12	" " "

Table CIV.—Sodium Chloride with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
117	1/1000	17.3365	0.0009 [1]	0	No corrosion.
118	1/100	18.1178	0.0009 [1]	0	" "
119	1/10	20.0233	0.0316	15	Green spots and streaks.
120	N	18.3372	0 0339	17	" " " "

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Table CV.—Sodium Chloride with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
225	1/1000	6.6189	0.1643	76	Badly corroded.
226	1/100	6.6663	0.1682	77	" "
227	1/10	6.5467	0.1497	69	" "
228	N	7.4723	0.1477	68	" "

Table CVI.—Sodium Chloride with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
229	1/1000	6.7869	0.0877	40	Badly corroded.
230	1/100	7.6427	0.0724	29	" "
231	1/10	7.0475	0.0273	13	Green streaks and spots.
232	N	6.8192	0.0159	7	" " " "

[1] Gain in weight.

Table CVII.—Sodium Chloride with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
233	1/1000	7.3540	0.0004 [1]	0	No corrosion.
234	1/100	6.5625	0.0048	2	Few minute green spots.
235	1/10	7.0781	0.0344	15	Green streaks and spots.
236	N	7.5965	0.0169	8	" " " "

Table CVIII.—Sodium Chloride with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
237	1/1000	6.3236	0.0001 [1]	0	No corrosion.
238	1/100	6.1297	0.0011 [1]	0	" "
239	1/10	6.6065	0.0250	11	Green streaks and spots.
240	N	7.5117	0.0271	13	" " " "

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Table CIX.—Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
245	1/1000	17.4359	0.0143	269	Greenish brown streaks.
246	1/100	17.9364	0.0102	194	" " "
247	1/10	16.8934	0.0053	108	Green spots.
248	N	17.0009	0.0024	46	Tarnished.

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Table CX.—Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
373	1/1000	6.5418	0.0125	156	Green and brown spots.
374	1/100	7.0031	0.0110	138	" " " "
375	1/10	6.8985	0.0054	68	Small green spots.
376	N	6.5718	0.0019	24	Well tarnished.

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Table CXI.—Sodium Sulphate with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
333	1/1000	19.2281	0.0170	321	Spots over surface.
334	1/100	19.4353	0.0142	268	Green spots.
335	1/10	18.1332	0.0125	236	Well tarnished.
336	N	19.3526	0.0104	196	" "

Table CXII.—Sodium Sulphate with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
337	1/1000	19.1982	0.0156	294	Green streaks.
338	1/100	18.3059	0.0140	264	" "
339	1/10	18.9705	0.0155	293	Green spots.
340	N	18.7855	0.0137	268	Whole plate dull green.

[1] Gain in weight.

Table CXIII.—Sodium Sulphate with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
341	1/1000	19.6320	0.0146	275	Well tarnished.
342	1/100	19.7485	0.0196	370	Green spots and streaks.
343	1/10	19.5355	0.0169	319	Badly tarnished. Several green spots.
344	N	19.2326	0.0117	221	Green streaks.

Table CXIV.—Sodium Sulphate with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
345	1/1000	18.4341	0.0045	85	Tarnished.
346	1/100	19.6283	0.0143	270	Green spots.
347	1/10	18.1347	0.0121	228	Badly tarnished.
348	N	19.0593	0.0117	221	Green streaks and spots.

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Table CXV.—Sodium Sulphate with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks
449	1/1000	7.3269	0.0174	218	Green spots and streaks.
450	1/100	7.6484	0.0202	252	Faint green streaks.
451	1/10	8.0451	0.0132	165	Dull colour.
452	N	7.4946	0.0134	168	Tarnished.

Table CXVI.—Sodium Sulphate with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
453	1/1000	7.7013	0.0181	226	Green spots and streaks.
454	1/100	7.5766	0.0200	250	" " " "
455	1/10	8.0451	0.0188	225	Green streaks.
456	N	7.4946	0.0134	193	Many small green spots.

Table CXVII.—Sodium Sulphate with N/10 Sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
457	1/1000	7.0807	0.0174	217	Many green spots.
458	1/100	7.4831	0.0176	220	" " "
459	1/10	7.7700	0.0191	239	" " "
460	N	7.9405	0.0142	178	" " "

Table CXVIII.—Sodium Sulphate with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
461	1/1000	7.0911	0.0067	84	Tarnished. Small spots.
462	1/100	7.6702	0.0182	228	" Large "
463	1/10	7.9916	0.0136	170	Large green spots.
464	N	7.8441	0.0122	153	" " "

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Table CXIX.—Sodium Chloride with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
349	1/1000	19.0371	0.0136	257	Many green lumpy spots.
350	1/100	18.8365	0.0139	262	" " " "
351	1/10	16.4222	0.0098	185	Greenish coating.
352	N	18.5260	0.0063	118	Well tarnished.

Table CXX.—Sodium Chloride with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
353	1/1000	18.9083	0.0096	181	Green streaks and spots.
354	1/100	17.0315	0.0130	245	" " " "
355	1/10	18.1345	0.0100	190	Small green spots.
356	N	17.5985	0.0115	216	Green coating.

Table CXXI.—Sodium Chloride with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
357	1/1000	18.1934	0.0068	128	Few green spots and lumps.
358	1/100	17.6379	0.0110	207	Green spots and streaks.
359	1/10	18.3824	0.0169	318	Green lumps.
360	N	18.2926	0.0159	300	Green coating and lumps.

Table CXXII.—Sodium Chloride with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
361	1/1000	18.4672	0.0020	38	Well tarnished.
362	1/100	18.1511	0.0044	83	Minute green spots.
363	1/10	18.1273	0.0135	257	Few green lumps.
364	N	18.2734	0.0151	288	Green lumps.

LOW CARBON STEEL. TEMPERATURE OF BOILING WATER.

Table CXXIII.—Sodium Chloride with N/1000 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
481	1/1000	6.7084	0.0169	210	Green coating with spots.
482	1/100	6.7072	0.0153	191	" " " "
483	1/10	8.0876	0.0123	154	Green spots and streaks.
484	N	8.2663	0.0071	89	Green coating. Tarnished.

Table CXXIV.—Sodium Chloride with N/100 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
529	1/1000	6.2168	0.0091	114	Dark green coating.
530	1/100	6.9987	0.0107	134	Green coating and spots.
531	1/10	8.1169	0.0159	199	" " " "
532	N	8.2188	0.0147	184	Green-brown coating.

Table CXXV.—Sodium Chloride with N/10 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
533	1/1000	7.1474	0.0087	109	Tarnished. Green colour.
534	1/100	6.7447	0.0131	164	Spots.
535	1/10	6.8138	0.0149	186	Green coating and spots.
536	N	7.4259	0.0164	205	" " " "

Table CXXVI.—Sodium Chloride with N/5 Di-sodium Phosphate.

No.	Normality.	Original Weight.	Gain in Weight.	Relative Cor'sion.	Remarks.
537	1/1000	7.5677	0.0016	20	Well tarnished.
538	1/100	6.6022	0.0073	91	Few green spots.
539	1/10	7.9037	0.0135	169	Green lumpy spots.
540	N	7.0790	0.0162	203	" " "

SUMMARY OF RESULTS

Room Temperature.

Sodium Sulphate.—1. In all cases di-sodium phosphate inhibits corrosion but not to the extent manifested by potassium di-chromate.

2. With N/1000 di-sodium phosphate, the rate of corrosion is only slightly reduced, but in solutions containing greater amounts of this salt, the degree of inhibition is much more marked.

3. The concentration of the sodium sulphate remaining constant, an increase in the amount of phosphate produces a decrease in the rate of corrosion. However, if the sulphate varies and the concentration of the phosphate remains constant, an increase in corrosive action follows.

4. With solutions containing N/100 or more of phosphate, the action of the electrolytes upon the iron is shown by the formation of dark green or greenish brown spots and streaks.

5. There is a noticeable difference in the behavior of the two types of test-plates.

6. When corrosion did not take place, the test-plates were found to be in the active condition, as they were readily attacked by 1.20 nitric acid.

Sodium Chloride.—The above summary describing the action of sodium sulphate and di-sodium phosphate also applies in a general way to conditions produced by solutions of sodium chloride and the phosphate. However, with the normal solutions an increase of phosphate from N 10 to N/5 will give a slight increase in the rate of corrosion. Further, if the phosphate is kept constant and the amount of sodium chloride is varied a decrease in corrosion sometimes results, especially with N/100 phosphate.

Temperature of Boiling Water.

1. It was found that if di-sodium phosphate be introduced into solutions of sodium chloride or sodium sulphate, an increase in the rate of corrosion of the test-plates was obtained.

2. In N/5 di-sodium phosphate there is a general tendency for the rate of corrosion to decrease.

3. The low carbon steel showed a higher rate of corrosion than did the commercially pure iron.

ACTION OF POTASSIUM DICHROMATE ON GALVANIZED IRON IN THE PRESENCE OF SODIUM CHLORIDE AND SODIUM SULPHATE.

The use of zinc was suggested some years ago as a means for preventing corrosion in boilers. Slabs of zinc were placed in the boiler in contact with the iron or steel, which was preserved at the expense of the zinc. This method for preventing corrosion was adopted on board ships and made particular use of by tramp steamers, the results being highly satisfactory. However, the great objection to the method is the rapid manner in which the zinc will go into solution under boiler conditions. As Dunstan and Hill[1] have shown that zinc can be passivified by means of potassium dichromate, and in view of the fact that this salt will greatly reduce the rate of corrosion of iron and steel in the presence of large amounts of common boiler salts at room temperature, as shown in previous experiments, it was thought that possibly the rate of solution of the zinc would be likewise reduced in the presence of potassium dichromate without hindering its action toward the iron. Accordingly solutions of varying concentrations of sodium chloride and sodium sulphate containing potassium dichromate in different amounts were made up, and test-plates of galvanized iron, similar in size to those previously used, were introduced into the solutions. Tests were run both at room temperature and at the temperature of boiling water for two weeks. The conditions under which the tests were performed were the same as given on p. 10.

In cleaning the plates after they had stood in the solutions great difficulty was experienced. After trying several means for cleaning them, it was decided to simply wash them thoroughly with water and then with alcohol and dry. It was found to be almost impossible to secure very good checks on the tests. This is attributed to improper means for cleaning, formation of zinc chromate, and to the great variation in the size of the crystals of zinc on the galvanized iron. The rate of solution of the plates in water was taken as a standard.

Tests were run with solutions containing varying amounts of potassium dichromate. The plates, after standing for a brief period, especially in the stronger solutions, became very bright; but at the end of the two weeks it was observed that much more zinc had gone into solution than when the plates were immersed only in water. This is easily explained by the fact that the addition of the potassium dichromate would increase the conductivity of the solutions and thus cause an increase in galvanic action.

A glance at the following results will show that the presence of potassium dichromate in either solutions of sodium chloride or sodium sulphate

[1] Transactions of the Chemical Society, vol. 99, p. 1861.

will stimulate the solution of the zinc rather than inhibit it. If the amount of potassium dichromate is kept constant and the concentration of the sodium chloride or sodium sulphate is increased, the rate of the destruction of the zinc is increased. Further, if the concentration of the potassium dichromate is varied and that of the sodium chloride or sodium sulphate kept constant, the rate at which the zinc is attacked is far more vigorous.

The plates immersed in the more concentrated solutions of potassium dichromate and sodium sulphate or sodium chloride were all of a yellow colour, the intensity of which depended upon the strength of the solutions. After these plates had been thoroughly washed with water, they were treated with hydrochloric acid to dissolve the zinc together with the yellow coating. The resulting solutions were tested for chromium. In every case this element was identified, much more chromium being found in the solutions obtained from the plates having the deep yellow color than those possessing a lighter color. Thus the yellow deposit on the galvanized iron was due to the formation of zinc chromate.

With the tests run at the temperature of boiling water no quantitative results were obtained. In every case the plates were badly attacked, and in some instances flakes of metallic zinc had fallen from the plates. In many others all the zinc had dissolved and the solutions had attacked the iron. This was especially true of the sodium chloride solutions.

GALVANIZED IRON. ROOM TEMPERATURE.

Table CXXVII.—Action of Water.

No.	Original Weight.	Loss in Weight.	Remarks.
A	5.9566	0.0023	No visible action.
B	6.1762	0.0029	" " "
C	6.2771	0.0038	" " "
D	5.9928	0.0032	" " "
E	6.0821	0.0026	" " "

Table CXXVIII.—Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
525	1/1000	5.8927	0.0039	130	No visible action.
526	1/100	6.1605	0.0021	70	Metal brighter.
527	1/10	6.3310	0.0064	213	Metal bright.
528	1/5	6.4807	0.0065	216	" "

GALVANIZED IRON. ROOM TEMPERATURE.

Table CXXIX.—Sodium Sulphate with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
485	1/1000	5.7442	0.0059	197	No visible change.
486	1/100	5.4649	0.0064	213	" " "
487	1/10	5.7579	0.0088	293	" " "
488	N	6.1893	0.0114	380	" " "

Table CXXX.—Sodium Sulphate with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
489	1/1000	5.5231	0.0159	530	No visible change.
490	1/100	5.8883	0.0320	1063	" " "
491	1/10	5.5643	0.0383	1277	Light yellow in color.
492	N	5.7842	0.0775	2583	" " " "

Table CXXXI.—Sodium Sulphate with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
493	1/1000	5.7247	0.0114	380	No visible change.
494	1/100	5.5725	0.0345	1150	Light yellow.
495	1/10	5.7728	0.0528	1760	Deep yellow.
496	N	5.4051	0.0649	2163	" "

Table CXXXII.—Sodium Sulphate with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
497	1/1000	6.0362	0.0171	570	No visible change
498	1/100	5.2548	0.0389	1297	Deep yellow.
499	1/10	6.0078	0.0950	3167	" "
500	N	5.7815	0.0986	3287	" "

GALVANIZED IRON. ROOM TEMPERATURE.

Table CXXXIII.—Sodium Chloride with N/1000 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
501	1/1000	5.8586	0.0052	173	No visible change.
502	1/100	5.8087	0.0097	323	" " "
503	1/10	5.3215	0.0061	203	" " "
504	N	5.1719	0.0097	323	" " "
505	3 N	5.5820	0.0145	483	" " "
506	5 N	6.1767	0.0210	700	" " "

Table CXXXIV.—Sodium Chloride with N/100 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
507	1/1000	5.9378	0.0062	207	No visible change.
508	1/100	6.0623	0.0248	827	" " "
509	1/10	6.1338	0.0398	1327	" " "
510	N	6.3237	0.0568	1893	" " "
511	3 N	6.0456	0.0675	2250	Light yellow in color.
512	5 N	6.0240	0.0691	2333	" " " "

Table CXXXV.—Sodium Chloride with N/10 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
513	1/1000	6.3159	0.0055	183	No visible change.
514	1/100	5.8117	0.0270	900	" " "
515	1/10	5.8750	0.0694	2313	Light yellow in color.
516	N	6.1337	0.0987	3290	Deep yellow.
517	3 N	6.0204	0.0981	3270	" "
518	5 N	5.9321	0.1130	3767	" "

Table CXXXVI.—Sodium Chloride with N/5 Potassium Dichromate.

No.	Normality.	Original Weight.	Loss in Weight.	Relative Cor'sion.	Remarks.
519	1/1000	5.9914	0.0018	60	No visible change.
520	1/100	5.9276	0.0282	940	" " "
521	1/10	6.0575	0.0713	2377	Light yellow.
522	N	6.1311	0.0909	3030	Deep yellow.
523	3 N	5.9955	0.0987	3290	" "
524	5 N	6.2547	0.1006	3353	" "

THE EFFECT OF THE ELECTRIC CURRENT AND POTASSIUM DICHROMATE IN VARIOUS SOLUTIONS UPON AN IRON ANODE.

A study of the behavior of an iron anode in various solutions containing potassium dichromate and heated to high temperatures was undertaken. A small boiler containing a pressure gauge, a safety valve and a common spark plug, which was screwed into the top of the boiler, was constructed. The entire boiler was made the cathode in an electric circuit and a small strip of iron suspended from the spark plug was used as the anode.

The iron strips which were used as anodes were made from commercially pure iron and had the following dimensions: 10 cm. × 0.50 cm. × 0.10 cm. The total area was 12.10 square centimetres. A small hole was drilled into the top of each strip so that it could be hooked on to A. When the plug was screwed into the top of the boiler, the iron strip would be completely covered by the solution. The hole in the strips decreased the area exposed to 11.97 square centimetres.

The boiler was heated by placing in a large paraffin bath.

N/10 solutions of sodium sulphate, sodium chloride, magnesium sulphate, and magnesium chloride were used. To these solutions potassium dichromate was added until they were also equivalent to N/10 and N/5 solutions of this substance.

In running the experiments the solutions, which would be at room temperature, were introduced into the cool boiler. The iron strip was then introduced into the solution, and the plug from which it was suspended screwed securely into the top of the boiler. The proper electrical connections were made, so that a current of two and a half amperes flowed through

the system. The boiler was then immediately placed in the paraffin bath and heated rapidly until a pressure of 120 lbs. was recorded upon the gauge. At the end of half an hour the boiler was removed from the bath, and when cool enough the current was stopped and the iron strip removed. In every case it was found that the iron would be in the active condition, as a large part of it had gone in solution during the half hour treatment.

Tests were then run starting with warm solutions containing normal (147 grammes per litre) potassium dichromate in N/10 solutions of the four salts previously used. Upon repeating the experiments as described above, the same results were obtained, the increase in the amount of potassium dichromate producing no effect. A warm solution was used at the start to dissolve all the potassium dichromate.

Thus it may be concluded that the possibility of keeping iron passive under boiler conditions with the aid of an electric current and potassium dichromate is practically impossible.

GENERAL CONCLUSIONS.

1. At atmospheric conditions the introduction of varying amounts of potassium dichromate into solutions of different concentrations of sodium sulphate, sodium chloride, magnesium sulphate and magnesium chloride, and saturated calcium sulphate, inhibit corrosion to a remarkable extent.

2. The differences in the chemical composition and physical properties of the iron and steel employed appeared to have practically no effect when placed in solutions of chlorides and sulphates containing potassium dichromate at room temperature. Differences in behavior were noted at the temperature of boiling water.

3. At atmospheric conditions a few of the test-plates were rendered passive by the dichromate contained in certain of the more dilute solutions.

4. The rate of corrosion was reduced in some cases upon the addition of dichromate to the dilute solutions at the temperature of boiling water.

5. In N/10 and normal solutions of the chlorides and sulphates the addition of dichromate to the hot solutions was decidedly injurious to the iron and steel.

6. The commercial application of potassium dichromate to boiler waters is not practicable because of cost and uncertainty of results.

7. Di-sodium phosphate limits the rate of corrosion of the iron and steel at room temperatures when added to various solutions of sodium sulphate and sodium chloride.

8. Di-sodium phosphate does not produce the passive state when iron or steel is immersed in its solutions.

9. Slight differences in the action of the iron and steel in solutions containing di-sodium phosphate were noted.

10. Iron and steel in solutions of sodium sulphate and sodium chloride containing di-sodium phosphate and heated to the temperature of boiling water, are more readily acted upon than if the phosphate were not present. Even small amounts of this salt increase the rate of corrosion.

11. The rate of solution of zinc occurring on galvanized iron is increased by the addition of potassium dichromate to solutions of sodium sulphate and sodium chloride.

12. Iron cannot be rendered passive under boiler conditions in N/10 solutions of chlorides and sulphates when varying amounts of potassium dichromate are added and the iron made the anode in an electric circuit.

The author of this paper is indebted to the Iron and Steel Institute of Great Britain for financial assistance given through the Carnegie Scholarship Fund.

VITA.

The author of this paper was born in Rose Bank, Staten Island, N. Y. He received his early education in the grammar schools of Brooklyn, N. Y., and graduated from the Commercial High School of that city in 1906. Immediately after graduation he accepted a position in the chemical laboratories of the American Brass Co. of Torrington, Conn., and was employed there until September, 1911. He then entered Clark College, Worcester, Mass., and received the degree of Bachelor of Arts from that institution in 1914. While a student at Clark some time was spent in the chemical laboratories of the American Steel and Wire Co. as assistant chemist. In the fall of 1914 he entered the University of Washington as teaching fellow in chemistry. The degree of Master of Science was granted in the summer of 1915. During this year papers on the "Total Amino Nitrogen in the Seedlings of the Alaska Pea" and the "Tannin Content of Pacific Coast Conifers", the latter with Dr. H. K. Benson, were published. In the same year a Carnegie Research Scholarship was received from the Iron and Steel Institute of Great Britain. The years 1916 and part of 1917 were spent in graduate work at the University of Washington. In June of the latter year, the examinations for First Lieutenant in the Ordnance Department were passed but no call into active service was received until December. Being among the first drafted in July of that year, he served a month at Camp Lewis as a private and two months with the Gas Defense Service, working in the laboratories of the National Carbon Company, of Cleveland, Ohio. As First Lieutenant he worked in the Geophysical Laboratory of Washington, D. C., the laboratories of Ohio State University, Johns Hopkins University, and of Edgewood Arsenal. All of the work performed in these laboratories dealt with the chemistry of war gases. In July, 1918, he was transferred to the Chemical Warfare Service with the rank of captain.